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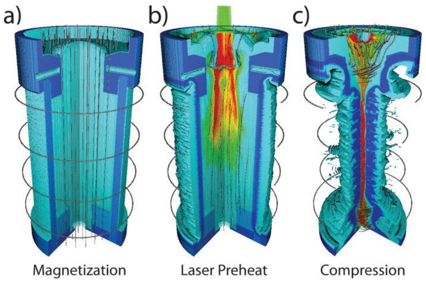
Neutron source reconstruction of one-dimensional neutron images with modified generalized expectation maximization algorithm

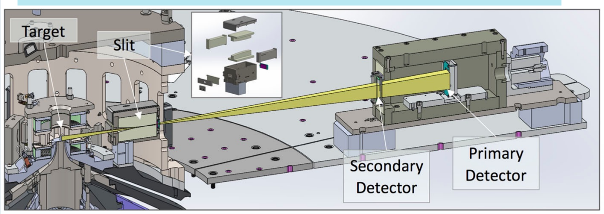
S. A. Ricketts[1,2], M. A. Mangan[2], P. Volegov[3], D. N. Fittinghoff[3], D. J. Ampleford[2]
[1]Texas A&M University, College Station, TX, USA
[2]Sandia National Laboratories, Albuquerque, NM, USA
[3]Lawerence Livermore National Laboratory, Livermore, CA, USA
sricket@sandia.gov



[1] P. F. Knapp et al., "Effects of magnetization on fusion product trapping and secondary neutron spectra," Physics of Plasmas., vol. 22, no. 5, 2015.

Introduction

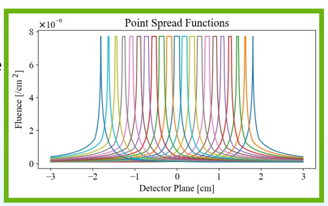
- A one-dimensional imager of neutrons (ODIN) comprised of a tungsten aperture, high density polyethylene (HDPE) converter foils, and CR-39 track detectors
- Images neutrons emitted from Magnetized Liner Inertial Fusion (MagLIF) experiments at the Z facility
- Forward scattering protons from the HDPE generate destructive tracks on the front face of CR-39 detectors which are exposed using a chemical etching process and recorded using an optical scanning system
- Tracks are down selected for primary DD-neutrons expected to have traveled directly through the slit assembly to the detector
- Neutron source profile reconstruction has been performed via a modified generalized expectation maximization algorithm that accounts for intrinsic background in the CR-39

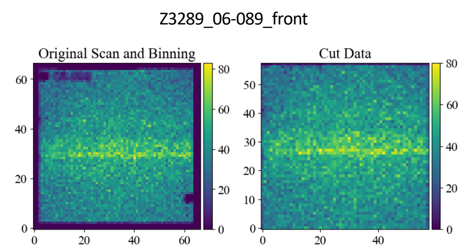


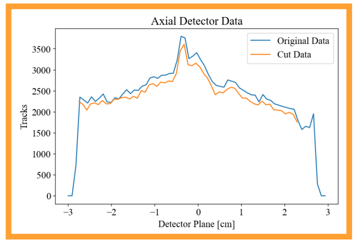
[2] David J. Ampleford, et al. "One dimensional imager of neutrons on the Z machine", Review of Scientific Instruments 89, 10I132 (2018)

ODIN Data Generation

- An analytical forward model of ODIN has been developed and used to generate response function matrices ($\mathbf{P}_{ij}$) needed to perform inverse problem calculations
- CR-39 tracks are integrated along the radial axis to generate a 1D axial detector response
- A subset of data is used to remove poor detection locations including alignment pinholes and serial number ($\mathbf{Y}_i$)





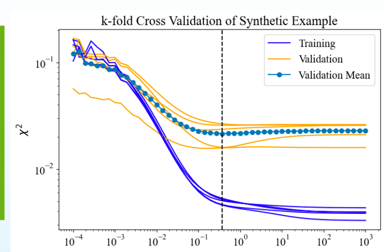


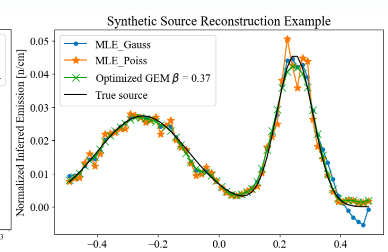
Source Reconstruction Methods

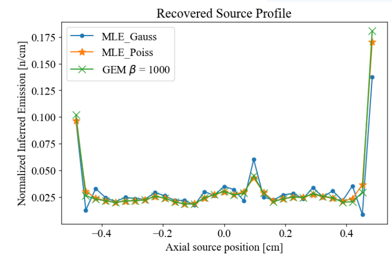
- The discretized Fredholm integral equation of the first kind can be solved for $\mathbf{G}_j$ via maximum likelihood estimation (MLE) algorithms which search for solutions that maximize the likelihood $L(G) = p(Y|G)$ given different constraints

$$\sum_{j=1}^{m} P_{ij} G_j = Y_i, i = 1,2,\ldots,n$$

- Such constraints are for Gaussian (MLE_Gauss) or Poissonian (MLE_Poiss) noise as well as a generalized expectation maximization (GEM) which implements a regularization parameter β
- Small β values smooth the solution and large β values approach MLE_Poiss
- A k-fold cross validation is used to determine the optimal regularization parameter



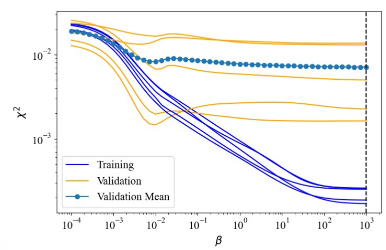


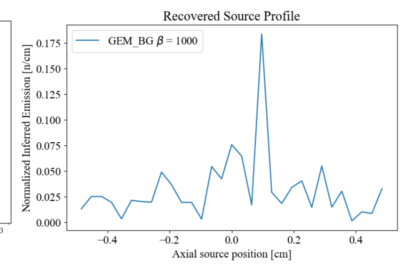


Modified GEM Algorithm

- Reconstructions of axial detector data created nonphysical edge effects caused by intrinsic background tracks in the CR-39
- A modification to the GEM algorithm (GEM_BG) was made to account for this background by adding three basis functions $\mathbf{B}_{ik}$ as additional response functions associated to new coefficients $\boldsymbol{\mu}_k$

$$[P, B]\begin{bmatrix} G \\ \mu \end{bmatrix} = Y$$





Conclusions and Future Work

- The modified algorithm successfully removed edge effects caused by intrinsic noise in the CR-39 and produced an accurate reconstruction of the neutron emission profile
- Uncertainty Quantification including of selection of β parameter
- Integration of multiple CR-39 scans to improve signal to noise ratio
- Comparison to other Z diagnostics including x-ray emission data

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